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# ADVANCED SYSTEMS TECHNOLOGY SECTION 1990 REVIEW AND 1991 WORK PROGRAM

Report No. 91-95-K

M.D.C. Moles, Acting Section Head
Advanced Systems Technology Section
Metallurgical Research

## ABSTRACT

The projects and achievements of the Advanced Systems Technology Section in 1990 are reviewed. Proposed projects and objectives for 1991 are described in outline.

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## EXECUTIVE SUMMARY

During 1990, the Department was rearranged, with the new Advanced Systems Technology Section being formed from the old NDE Unit and the automated welding part of the Metallurgy Section. The AST Section was divided into the Non-destructive Evaluation Unit and the Automated Systems Unit.

As in previous years, the NDE Unit concentrated mainly on pressure tubes, with long, short and firefighting projects. The Automated Systems Unit was less concentrated on pressure tubes, with interests in hydraulic generation and construction as well as nuclear.

During 1990, progress was made on several NDE projects. Specifically, a laboratory technique for detecting tight garter springs was developed; this system is planned for CIGAR in 1991. While some progress was made on hydride measurement by nonlinear ultrasonics, the most promising short-term developments were in the use of conventional velocity measurements. An EMAT device for on-power ultrasonic inspection is now starting to look viable.

Throughout the year, much emphasis was placed on defect identification and sizing. Specifically, many machined defects were characterized using ultrasonic B-scans, and time-of-flight diffraction was used to size them. These techniques were used on a defect from Bruce 1 W19, and generated a reliable profile. Modelling was successfully used to predict the shape of the image as a function of defect sharpness.



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Work was also performed on inservice inspection systems, specifically CIGAR, BLIP and SLAR. For BLIP, further software and hardware modifications were performed. The uncracked blister detection module was used successfully on CIGAR for detecting damage in Pickering 4. For SLAR, a modification to the eddy current gap measurement was developed, using deconvolution techniques.

For eddy current, the on-power SLAP coil completed its lab tests, and has been passed to CRNL for development. Other eddy current work involved swept frequency and probe modelling. Ultrasonic deconvolution techniques using the L1 norm approach are becoming successful. In other NDE areas, acoustic emission of leaking pressure tubes using an expert system in the laboratory is proving successful.

A patch scanner for the Bruce Heavy Water Plant is being prepared. An automated welding, grinding and inspection system for the Concrete Integrated Container is being planned.

In Automated Systems, work continued on SPIDER (Self Propelled Inspection Device for Evaluating Reactors), with underwater motor and helical cabling. Work started on a sealing mechanism for containing the Tashiro heating tool for measuring hydride concentration in pressure tubes, using eddy current to measure resistivity. An automated ultrasonic inspection system for steam generator tubing using a multi-element transducer was near completion.

A new computer system was developed for the Bruce STEM. An LVDT mechanical calliper and an EMAT-based ultrasonic system were developed for measuring the wall thickness of ring thermal shield support brackets. A special probe pan was developed for Pickering LP turbine disc inspections. A video was made of the robotic inspection of a prototype titanium diffusion bond for a nuclear used fuel container final closure weld.

A microprocessor-based controller for an advanced pipe welding system was developed. A demonstration was given for the automated gouging and repair for hydraulic stations headgate roller paths. For repair of hydraulic turbine runners, improvements have been made to the robotic system.

For 1991, work in NDE will continue to emphasize pressure tubes, especially defect characterization and hydride measurement. Other NDE areas will include steam generators and calandria vault inspections. In automated systems, there will be less emphasis on fuel channels though work will continue on sag, SPIDER and hydride measurement. Delivery systems for turbine disk inspection, ring thermal shield support brackets and steam generators will be modified. Work on hydraulic station repair will continue.

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To Dr. D. Mills
Director of Research

# ADVANCED SYSTEMS TECHNOLOGY SECTION
# 1990 REVIEW AND 1991 WORK PROGRAM

## I - INTRODUCTION

The highlights of the Advanced Systems Technology Section's 1990 work program are outlined in this report, followed by the proposed 1991 work program.

Both the NDE Unit and the Automated Systems Unit received significant COG (CANDU Owner's Group) long-term research funding, particularly NDE. NDE also received funding from CPSD Inspection and Maintenance, primarily for shorter-term projects, with small sums from other areas such as hydraulic, thermal and nuclear waste. Automated Systems had more diversified funding sources, including hydraulic, Canadian Electrical Association, CPSD Chemistry and Metallurgy, and Design and Construction. The Section performed a balance of long and short term work, though Automated Systems concentrated more on completed delivery systems. As with previous years, students performed a very useful role. Financially, the Section's OM&A expenditures were within budget.

### Section Personnel

| | |
|---|---|
| *Senior Research Engineer* | M.P. Dolbey |
| *Engineers* | M.J. Tinkler<br>W.K. Chan<br>S. Kramer<br>D. Donnelly<br>E. de Buda<br>J.H. Sedo<br>D. Mair (Temp)<br>T. Writer (Temp) |
| *Technologists* | A.L. Allen<br>E. Bernacchia<br>J.R. Antonacci<br>K. Yiu |

| | |
|---|---|
| *Technicians* | J.R. Boon<br>G.E. Truemner<br>F.C. Earl<br>K.C. Watt<br>C. DeAraujo |

The objectives and principle research interests of the Section are:

(1) Developing techniques for inspecting nuclear reactors, primarily pressure tubes, and;

(2) Design and build automated delivery systems for inspection, welding etc.

## II - 1990 WORK PROGRAM REVIEW

### NUCLEAR GENERATION

#### General

**Automation and Robotics in Construction**

It has been recognized within the Design and Construction Branch of Ontario Hydro that any future generating station construction must embrace advanced technologies to assure substantial schedule and cost reduction. A Branch Steering Committee, with OHRD representations, has been established under the auspices of the Construction Development Unit, Construction and Services Division, to identify and coordinate construction automation and robotics work programs for the next few years. Current emphasis is on welding and related (eg. grinding, inspection) technologies, with several possible project areas now being considered. A needs and opportunities study was initiated in November to help determine where the greatest potential cost and schedule savings may be realized by implementing robotics and/or automated systems into existing plant construction activities, as well as construction work in support of operating plant maintenance and rehabilitation. In the meantime, support is being given to research efforts in automated pipe welding, continuous wire welding consumable evaluation, and laser sensor seam tracking. Other possible initiatives could include automated UT inspection for pipe welds, a robotic work cell for fabrication shop operations, and automated grinding stations for weld crown removal.

Related to this, the 7th International Symposium on Automation and Robotics in Construction was attended in Bristol, U.K. The symposium provided a valuable overview of the technology, identifying current applications (mostly in Japan) as well as future trends and areas for R&D.

**Advanced Pipe Welding System Development**

The first phase of this project was to develop a microprocessor-based controller, for a commercially available mechanized pipe welding system (Magnatech con-

troller and weldhead, Fronius P-GMA welding power supply). A prototype system has been assembled and partially tested. It consists of a main controller, along with a remote setup pendant controller and a remote hard wired weld pendant. This microprocessor control allows the preprogramming of a varying number of changes within a weld pass and during the total multi-layer cycle with minimum operator intervention. The operator is also able to trim various parameters during welding that were previously unavailable for trimming. In particular, the operator can use one knob to match the oscillation amplitude and associated variables with the width of the weld joint preparation as it increases with each weld layer.

**Multichannel Acoustic Emission System**

A multichannel acoustic emission system (MAENADS) was developed incorporating 32 independent AE amplifiers interfaced to a Macintosh computer. The interface and control software were developed in the LabView environment. Detection and counting of acoustic emission events on up to 32 channels is now possible.

**EC Probe Modelling**

A U of T engineering student was hired for the summer to help extend the EC probe models that have been constructed for the CIGAR gap measurement project. Currently, the probe is characterized by a function that describes its axial and rotary variation in sensitivity. The function form is simple and is based on a combination of heuristics and laboratory experiments. It is also a real valued function as only one component of the complex EC signal is of interest for gap measurement. The goal of the research project is to use electromagnetics to derive a more exact, complex valued sensitivity function and see if it can successfully predict the full EC signal. It is hoped that the results will have application not only for the gap system but also for flaw signal characterization and sizing problems as well.

**Swept Frequency EC**

A technique has been developed to quickly and accurately measure the EC disturbance vector over a wide range of operating frequencies. Experiments with a number of artifacts in both pressure tubes and heat exchanger tubes have produced results that are in good agreement with theoretical predictions. Various 2D plots of the data may be used to aid in the selection of operating frequency and probe type for standard EC inspections, the characterization of EC indications and possibly the sizing of flaws. A variety of software packages for 3D data have been used to try and visualize all the information in the data at once. However, no clear improvement over the 2D plots has yet been achieved. Work will continue to define the capabilities of this new technique and to apply it to suitable applications.

**Bruce Heavy Water Plant Patch Scanner**

Bruce Heavy Water Plant personnel required the ability to ultrasonically inspect rectangular sections of thick walled vessels and piping. This was necessary to

monitor blister growth and cracking which had been observed through manual ultrasonic inspections. We proposed an automated system which would attach onto the structure being inspected via magnetic wheels and propel itself via servo-motors while doing the inspection under computer control. Construction of the prototype system is now approximately 80 percent complete and laboratory testing will begin in early January. Software development is progressing well and the ultrasonic development will continue as soon as the prototype hardware is ready.

Out-Reactor Components

**Software Simulation Packages for Automated Systems Development**

It has recently become apparent that a number of sophisticated, software-based robotic development tools are currently being used in industry to allow users to quickly generate 3D animated work cells on a computer screen to simulate and assess the operation of robots, remote tooling and mechanized or automated equipment. This has seen particular growth in the automotive industry, but recent conference presentations have reported applications where such software has been used for designing, developing and demonstrating, in simulation, tooling for in-reactor inspection and maintenance, eg. in Germany, United States, England and France. Moreover, this type of animated visual presentation is proving to be an invaluable tool for operators of remotely manipulated (ie. teleoperated) systems, eg. for in-reactor inspection and maintenance. Work has begun to assess the capabilities and potential benefits of this type of computer-aided design software for automated system and remote tooling development in Ontario Hydro. Contacts have been made with distributors of three such packages, ROBCAD, IGRIP and GRASP, and consideration has been given to the kind of computer work stations upon which these will best run.

Fuels & Reactors

**Acoustic Emission Monitoring for Leak Detection in Pressure Tubes**

Considerable progress was achieved in extending the capability to acquire and process acoustic emission leak signals. An acoustic emission system of hardware, acquisition software and analysis routines has been assembled. Excellent discrimination between high and low temperature pressure tube leaks has been demonstrated.

**$H_2/D_2$ by Ultrasonics**

Hydride platelets in pressure tubes lower fracture toughness. Many ultrasonics techniques have been tested to see if they will detect concentration, however, only two of these have shown any promise.

Differential velocity measurements involve measuring the difference in the transit times of two different acoustic waves travelling along the same path. Two potential pairs of such waves have been shown to work. The first pair are the Lame

plate modes which are generated by EMATS and travel around the circumference to the tube. The second pair are the longitudinal and mode converted shear waves generated by a normal beam probe. The Lame mode method has the advantage that there is a long path length while the normal beam method is easier to implement.

Acoustic nonlinearity measurements involves studying either how velocity changes with pressure or temperature or how the frequency changes with the acoustic pressure or temperature. Measurement of the rate of change in the difference in the transmit times of Lame modes with the internal pressure in the pressure tube has been shown to depend on hydride concentration. A dip in the graph of acoustic velocity with temperature has been noted at TSS. The rate of harmonic generation in the field of two strong acoustic waves has been noted to depend on hydrides.

**EC $H_2/D_2$ Measurement**

The EC probe used to monitor the resistivity change in a pressure tube during heating or cooling was redesigned and became operational this year. The effectiveness of the new design in producing an EC signal due only to the thermally induced changes in the pressure tube was successfully demonstrated. The flow of coolant through the probe and the ceramic fibre insulation between the probe and heaters kept the temperature change of the probe moderate in comparison to that experienced by the pressure tube. The effect of this small temperature change on the EC probe was minimal due to the use of a constant current send-receive design, low expansion materials and an O-ring support mechanism. The end result was that a thermal cycle of the heaters without the pressure tube around the probe produced a change in the EC signal that was insignificant in comparison to that observed with the tube in place.

EC and temperature data has been collected during the cooling cycle of the pressure tube by a PC based data acquisition system. The plot of dEC/dT vs. T, used to estimate TSS and H2/D2 concentration was noisier than desired and also a somewhat different shape than expected. Work is underway to address these issues.

**On-Power UT Inspection of Pressure Tubes**

Initial evaluations of the EMAT device proved very encouraging in the area of defect detection. The addition of an automated system has been completed for motion control and data acquisition. B-scans and C-scans have given excellent results in the study of wave behaviour and flaw detection.

The EMAT system generates lamb waves for acoustic sensing which have not previously been used in this laboratory. In order to establish a theoretical basis on which to develop defect detection techniques the behaviour of this acoustic mode must be well understood. Programs were written to generate dispersion curves for phase and group velocities and for the spectrum of wavelengths at various fre

quencies. As well, dispersion curves were generated for frequency vs. wavelength.

Work began on 'return signal' analysis for the detection of fretted areas. Computer simulations were done and piezoelectric transducers used to map the energy irradiated by the EMATs inside a pressure tube. A contract was also awarded to George Alers (developer of the EMAT device) to map the irradiated energy and determine the susceptibility of the return signal to factors such as tube wall thinning. Underwater tests have been performed and showed very little decrease in signal strength.

**Piezoelectric Transducers**

Tests were performed on one high temperature contact transducer. Due to the difficulties associated with high temperature couplants, results were difficult to achieve. A high temperature immersion transducer has been ordered that may eliminate many of the problems associated with contact testing. Tests at this time remain inconclusive.

**Deconvolution for Pressure Tube Defect Detection and Sizing**

Advances have been made in the development of digital deconvolution techniques for the improvement of ultrasonic defect detection and sizing. A number of deconvolution methods were examined and compared including full L1 and L2 algorithms as well as one-at-a-time spike extraction techniques. Deconvolutions were carried out on simulated data sets and with real signals obtained on pressure tube material.

In addition, various "quality" measurements have been explored in an effort to best quantify the relative merits of the deconvolution techniques. It appears as if some combination of factors will be required to ensure that spikes are both optimally located and of the correct amplitude.

A comparison of the L1 and L2 methods has been made with regard to specific types of corrupting noise, Gaussian, uniform, and heavy-tailed noise. In all cases, and using every measure of "quality", the L1 (least absolute values minimization) method has been demonstrated to be far superior to the L2 (least squares minimization) approach. Indeed (almost paradoxically) the L1 method surpasses the least squares approach even when the "quality" factor is the sum of the squared errors!

**Alternate Representations of Digitized NDE Signals**

A number of new methods of NDE digital signal representation have been evaluated in order to present valuable information which is hidden in the traditional time and frequency domain representations. A full evaluation of the Wigner distribution function, the short time Fourier transform, and the Choi-Williams distribution has been completed. These methods provide a method of viewing the time

and frequency relationships simultaneously in an understandable way by mapping a one dimensional amplitude-time signal to a two dimensional amplitude-time-frequency domain. The relative merits and shortcomings of these techniques have been investigated, using a variety of test signals including single frequency tones, multiple discrete frequency signals, and chirp signals. In addition tests were performed on ultrasonic transducer pulses.

**Digital Recovery of Ultrasonic Garter Spring Signals**

A ultrasonic method for the detection of tight garter springs under load has been developed. The technique has the advantage of being usable at typical CIGAR inspection speeds with the replacement of a single transducer. The small oscillations in reflected ultrasonic energy caused by the presence of a garter spring are digitally enhanced based upon a knowledge of the garter spring helix spatial frequency. Increases in signal strength of a hundred or more are typical.

**SLAP**

A single prototype of the on-power EC garter spring detection probe and its support structure has been completed. The probe has a detection performance similar to that of the CIGAR garter spring probe but is fabricated using ceramic insulating materials and is completely enclosed in a welded titanium case. The prototype was tested in an autoclave while immersed in water at 318° and 1600 psi. Although it was not possible to generate a representative garter spring signal during the test, no unusual effects were observed in the baseline signal. The probe was unaffected in any significant way by the autoclave test as evidenced by the fact that garter spring detection performance remained equal to pre-test results.

In preparation for radiation tests at NRU, the prototype was manufactured to a QA level of 2299.4 and helium leak tested after pressurization in the autoclave. Radiation test plans being prepared by CRNL staff and will be carried out under a new COG project in WP #37.

**SLAR Gap Measurement**

The SLAR gap system was reviewed by CRNL and OHRD staff. A number of improvements have been identified and some have been implemented. One of the more significant changes has been an improvement in the method used to compensate the EC signal for the effects of pressure tube thickness variations. The new method now accounts for the different way in which the EC probe and the UT thickness probe sense the variations. Previously, errors were observed in tubes with double and triple rotary thickness lobes because the UT probe could accurately track these rapid changes but the EC probe could not. Preliminary testing of the new compensation technique on the SLAR system at AECL-SPEL shows a significant improvement, especially in the previous problem tubes.
The new technique is similar to that developed for the CIGAR gap system but simplified to work within the SLAR constraints. One significant improvement over

the CIGAR system is the manner in which the parameters that characterize the EC probe are determined. A new deconvolution technique, one which is able to constrain the solution to the desired functional form, is used to determine the parameter values which minimize the L2 norm between the observed and modelled EC thickness response. This method produced robust parameter estimates, even with noisy data, and allowed some idea of confidence limits to be determined.

**Pickering Unit 4 - Uncracked Blister Detection (UCBD)**

An ultrasonic test (UT) method was developed for detecting uncracked hydride blisters in pressure tubes. The technique uses high frequency transducers in a high angle transmit-receive mode. Evaluation of the system was performed on laboratory grown hydride blisters and the metallographic depth of the blisters was estimated by measuring changes in the ultrasonic time of flight. Hardware was fabricated to apply the method to the CIGAR system and CPSD CIGAR operators were trained in its use. Approximately 50 fuel channels in Pickering 4 (identified by BLIP as probable contactors) were inspected with the system. Both the BLIP and CIGAR flaw detection systems detected areas on the outside surface of some P4 pressure tubes that are believed to be water deposit or thick zirconium oxide. These areas, which are not at contact locations, had an UCBD response similar to blisters but no time of flight change was observed on these indications. Special attention was paid to three channels in which scraping had shown hydrogen levels to be high. All had responses that could be interpreted as either blisters or OD patches. In one of the channels, F-15, a clear increase in the time of flight was observed which was interpreted as being due to a thin hydride layer. In channel C-17 small variations in time of flight were interpreted as possible hydride but more probably effects of inside surface variation. Both these tubes have been removed and metallography has shown that a thin layer of hydride was present in C-17 but not in F-15. The cause of the increased time of flight in F-15 has not yet been determined. Further work is planned to investigate this question.

**SLAR - Wall Thickness Measurement System**

Production trials of the SLAR (Spacer location and Repositioning) System indicated a need for improvements in the gap measurement sub-system of which the wall thickness measurement is a part. A proof test procedure was developed to exercise all aspects of the system to assure it met the design specifications. The procedures have been used during acceptance testing of the G2 SLAR system. The Wall thickness system passed successfully but the test showed up deficiencies in other supporting systems that had not previously been discovered.

**SLAR - Blister Detection System**

The SLAR blister detection system performed well during production trials in Bruce Unit 2 in 1989 but a similar system used with BLIP in Pickering Unit 4 in mid 1990 resulted in a large number false calls, i.e. high response from contact areas suggesting the presence of blisters. A proof test procedure was developed to exercise all aspects of the system to assure it met the design specifications. A

number of significant deficiencies were found during this development. The transducer calibration was found to be very sensitive to alignment of probes and tool with respect to the calibration reflector, a 6.3 mm long OD circumferential notch. The use of a flat bottomed hole reflector has eliminated this problem. Another source of error was due to variation in sensitivity along the length of the 20 mm long probes. A procedure for characterizing the probes has been developed and over 200 have been tested. Based on the results , a revised manufacturing specification has been written and new probes ordered. Approximately 50% of the original probes have to be replaced. Finally, a problem that affected the operation of the BLIP system was high background response at operating sensitivity. This was found to be due to poor probe damping causing reverberation in the case. It was eliminated by a manufacturing change made in 1988 and all the old type probes have been replaced. A recent repeat of the proof test indicates that the system now meets the design requirements. The system documentation is being revised to reflect the changes .

**CIGAR - System Upgrades**

Assistance has been provided to CPSD for various improvements to the CIGAR system.

Precision ring specimens used for calibrating a pressure tube gauging system were measured and recertified.

New calibration rings for Bruce CIGAR inspection head carriers have been designed and manufacturing is near completion. New calibration rings for Pickering carriers are now being designed.

Electrical noise filters, originally designed for use with SLAR, were provided to CIGAR for evaluation to see if their use would reduce noise being picked up by the ultrasonic inspection systems. Initial tests indicate improved performance.

**CIGAR - Ultrasonic Flaw Characterization Methods**

Exerience has been gained in the interpretation of pressure tube flaws using the GDCPS (Generalized Data Collection and Processing System). Artificial axial ID flaws of various shapes and depths have been manufactured and studied with normal beam, circumferential and axial pitch catch methods. Libraries of responses have been collected and signal interpretation methods developed. At present, the techniques work well for flaws > 0.5 mm deep that are open and regular. Modelling and experimental work on improved techniques continue.

**CIGAR - Characterization of Dispositionable Pressure Tube Flaws**

The CSA code applicable to pressure tube inspection requires that flaws with ultrasonic responses equal to or greater than the response from a 0.15 mm deep notch must be analysed to demonstrate continued fitness for service. This re-

quires that the nature of the flaw and its length, width and depth be determined by inspection.

Periodic and in-service inspections using CIGAR have shown that one type of flaw, debris damage, is very widespread. Debris damage flaws are randomly oriented and shaped pits fretted into the inside surface of a pressure tube by fragments of "debris" assumed to be left during reactor construction/commissioning. The debris lodges between the fuel and the tube and flaw vibration causes fretting. Although most damage is shallow, an unsettlingly high proportion of inspected tubes contain dispositionable flaws. Three pressure tubes, all from Bruce Unit 1, have been replaced because they contained debris damage flaws ranging from 0.8 to 1.6 mm deep (20 to 40% throughwall extent).

At present, the primary nondestructive method for characterizing flaws and measuring their depth is ultrasonic pitch-catch and normal beam B-scan evaluation developed by OHRD NDE group. During 1990 the following flaw evaluations were performed for CPSD.

| *Station* | *P.T.* | *Indication #* | *Depth (mm)* | *Date Reported* |
|---|---|---|---|---|
| Wolsung 1 | M-11 | Indication #1 | 0.3 | 90-05-02 |
| Gentilly 2 | Q-11 | Indication #1 | 0.6 | 90-09-07 |
| Pickering 4 | E-15 | Indication #1 | 0.2 | 90-10-29 |
| Bruce 5 | A-08 | Indication #1 | 0.3 | 90-11-29 |
| Bruce 1 | K07 | Indication #2 | 0.8 | 90-12-17 |
| Bruce 1 | V04 | Indication #2 | 0.1 | 90-11-14 |
| Bruce 1 | V06 | Indication #1 | 0.1 | 90-11-14 |
| Bruce 1 | W19 | Indication #1 | ~ 1.5 | 90-11-13 |
| Bruce 1 | X11 | Indication #2 | 0.5 | 90-11-14 |
| Bruce 1 | X11 | Indication #3 | 0.1 | 90-11-13 |
| Bruce 1 | X11 | Indication #5 | 0.2 | 90-11-13 |

**BLIP (Blister and Spacer Location with PIPE)**

The BLIP system, developed jointly with D&D and CPSD in 1989, was commissioned and used for the first time in Pickering Unit 4 in Mid 1990. An unresolved problem from the development phase was the provision of suitable inspection head

axial position information to the inspection computer. This was overcome by replacing a spare fuelling machine axial potentiometer with a digital encoder. Assistance was provided to CPSD during commissioning of the system and data interpretation. Approximately 300 Pickering 4 pressure tubes were inspected in less than 30 days.

**Development of Improved Rolled Joint Inspection Methods**

AECL-SPEL are performing pressure and temperature cycling tests on fuel channel pressure tube to endfitting rolled joints (RJ) made using the various rolling procedures employed in different reactors. The NDE group has been inspecting the joints after the tests to determine if there is water in any of the joint grooves. Water has been found in some joints and further inspection of those joints has been performed in an attempt to improve the methods available for determining leak paths. It has been demonstrated that water in a RJ groove easily flows around as the joint is rotated and that the water can be detected from the outside of the endfitting hub. This will allow monitoring of the joints between pressure and temperature cycles without removing them from the test rig.

**Defect Depth Measurements by Ultrasonics**

The objective of this program is to develop ultrasonic techniques for measuring defect depth measurements, primarily for ID flaws. Given the success of the uncracked blister module, the emphasis all year has been on ID defects. A summer student (WRF) modified and improved the crack-tip diffraction technique developed earlier for measuring crack depths in blisters. As before, flat 20 MHz transducers were used initially at 45, 55 and 65° refracted angles, with SAFT to improve the signal-to-noise ratio. These crack-tip diffracted signals proved to be very low amplitude, and the hyperbolae very flat, resulting in poor signal detectability and little improvement in signal-to-noise ratio on SAFTing.

Later, standard CIGAR 10 MHz focussed transducers were used in a standard CIGAR head, and these generated much higher amplitude signals. In contrast to the flat transducers, the CIGAR transducers generated an "X" signal at the defect tip. This X-pattern proved to be very robust and reproducible, and an image enhancement process was developed called FTC - Focussed Transducer Compensation. The FTC technique worked well on notches, with accuracies of $\pm$ 0.1 mm. On laboratory-grown fatigue cracks, accuracies of $\pm$ 0.2 mm on the estimated depths of the latter were obtained.

Initial modelling (WRF) showed that the characteristic X-pattern of the cracks could be due to an asymmetric pulse/ receive from the focussed transducers. This approach was based on estimating the time of arrivals of the various edge and plane waves, to build up the appropriate "X".

Subsequently, a more rigorous model was produced (HDM) using basic wave equations, which showed clearly that the X-pattern was due to plane wave-edge wave interaction. Though this model made some simplifying assumptions, the re-

sults clearly reproduced the X. Interestingly, very little diffraction work has been performed on focussed transducers in the world NDE community, so this X-pattern was essentially an unexpected bonus. Overall, the modelling has shown that sharp defects generate an X, whereas blunt defects do not. Analysis of pitch-catch B-scans from reactor defects should allow us to differentiate sharp from blunt defects in reactor using this type of approach.

FTC can be applied directly to in-service B-scans. Pitch-catch B-scans on one of the ID defects found in Bruce 1 W19 were analyzed in the light of these experimental and theoretical results. The analysis showed first that the defect was 1 to 2 mm deep, and second that the defect probably had a sharp tip, in contrast to most of the debris fret marks observed to date.

**High Frequency Ultrasonics**

The objective of this program is to develop 1) high frequency transducers for non-radiation use, and 2) high frequency transducers for in-service use.

During the year, a number of transducers were fabricated by a local supplier (Ginzel Brothers) using polymer and co-polymer elements. The prime objective of these transducers was to replace the high frequency PZT transducers currently used on the manufacturing inspection. These PZT transducers have proved to be highly variable and very difficult to use due to their short focus and large number of multiples. Suppliers on other countries have made high frequency coplymer transducers, but prices are typically many times those from our local supplier, and delivery much longer.

This project concentrated on making PVDF and PVDF-PTFE transducers by gold-plating commercial sheets,and following the procedures developed at the University of Toronto/Princess Margaret Hospital. As the conventional pulser proved inadequate, a custom pulser system (Avtek) was purchased. The overall aim was to deliver a series of CIGAR-type focussed transducers at 50 - 100 MHz, reproducibly, cheaply and reliably using either polymer or copolymer elements.

Initial results were quite good, until the limits of the new pulser became apparent during the summer. The organic elements have much lower energy than similar PZT elements, resulting in lower signal amplitudes and signal-to-noise ratios. This is partially offset by their improved coupling coefficient. The copolymer elements have better energy than the equivalent polymer elements, but are more fragile and have reduced bandwidth.

The ultimate test for nonradiation environments is the transducers' ability to detect the Bruce 2 N06 lap defect in the remaining offcut. The offcut was tested using a variety of late-model transducers and the Avtek pulser. Overall, the transducers were able to detect B2N06, but at slightly lower amplitude than the current PZT system. However, as indicated before, the current manufacturing inspection system has proved difficult to operate reliably, so an organic element system has a

major advantage overall. (Note that current CIGAR transducers do not detect B2N06 at all).

The local supplier has largely overcome the manufacturing problems inherent in making these organic element transducers so frequency, backing and focussing are very consistent. The main manufacturing problem remaining is pinholes in the organic sheet from the first supplier. However, this may be solved by moving to a second supplier who uses a different technology.

From a technical viewpoint, the organic elements have the inherent weakness of low energy, but this may be somewhat offset by more improvements in pulse-shaping and by increased voltage. These developments will probably be done in conjunction with OHRD during 1991, but not at COG's expense.

Overall, the project can be summarized as saying that we have now developed a reliable supply of low cost, high frequency organic transducers, and would be able to build a better manufacturing inspection system, if required. A slight time delay might produce an even better system, which would match the current PZT system, but be much easier to use. Detecting carbides in pressure tubes has not been investigated yet, but may be in 1991. Radiation tests on organic transducers is underway, funded by CPS for CIGAR applications. The local transducers are as good as imported versions, and much cheaper and faster.

(From a research aspect, this project has provided very useful seed technology. A variety of customized organic element transudcers have been made, for measuring hydride concentration in pressure tubes, scanning steam generator tubes, and other applications, at low cost and rapid delivery).

**Bruce S.T.E.M. Development**

A new computer system has been developed for the Bruce STEM (Scanning Tool for Elongation Measurement) system. The computer system, which includes a portable COMPAQ 386 computer and special I/O boards, has been integrated with the existing STEM remote consoles for Bruce A & B.

During 1990, the computer system was tested at Bruce Unit #8 in June, and at Bruce Unit #6 in September. A new software package for providing graphic and data presentation on-line was also implemented for the pressure tube elongation measurements. This software provides the operator with on-line information about the quality and quantity of the data being measured. During the course of STEM measurement on Unit #6, some computer system errors were detected. The cause of this operating problem was later identified and a solution was implemented.

The computer system allows the P/T elongation measurement to be faster, provides more accurate data recording, and minimizes unnecessary manual recording errors. This computer program runs in the Microsoft Windows operating environment and allows users to operate 2 different data collection systems (Bruce and Darlington) using the same software interface.

**Darlington - Pressure Tube Elongation Measurement**

Monitoring equipment is required to periodically measure the elongation of pressure tubes at Darlington NGS. Because of certain differences between the reactor designs, the measurement equipment for Darlington has been designed differently from those for the Pickering and Bruce reactors. An airborne ultrasonic STEM distance measurement equipment was developed and then tested twice at Pickering NGS in 1989. Since then, two ultrasonic STEM devices were built to provide an RS422 interface for a long distance data transmission. This equipment is ready for installation and site test.

During the previous Pickering tests, the measurement accuracy of the ultrasonic detector was somewhat affected by the heat distribution across the scanned areas. In addition, this ultrasonic device is also very expensive. In 1990, we investigated the possibility of using a low cost laser displacement sensor to replace the ultrasonic transducer for Darlington STEM. Laser displacement sensors from two different manufacturers were evaluated, and the results showed that they provided more reliable and much more accurate measurements. One of these laser detectors could measure distances up to 150 mm. Further testing will be required to ensure that the laser can withstand the working radiation environment. A number of technical problems associated with the construction of such a measurement head need to be resolved prior to applying this laser detector for STEM.

**Calandria Vault Ring Thermal Shield Support Bracket Wall Thickness Measurement**

Following a request from CPSD, two types of thickness measurement devices were developed for the RTS (Ring Thermal Shield) bracket inspection associated with the B & W ANDREA robot arm. An LVDT mechanical caliper and a near-commercial EMAT (ElectroMagnetic Acoustic Transducer) device were specifically built/obtained for the thickness measurement. Both the EMAT and the Caliper were attached to the ANDREA arm which was designed for use from the south Accessible Area (access through 8" diameter horizontal portholes).

Between March 9 to 12, thickness measurements of two lower carbon steel RTS brackets were taken from the upper west porthole of the south accessible area. Both the EMAT device and the caliper were used. In general, the measurements from both techniques were consistent, although the LVDT caliper readings were higher than the EMAT results. This is likely due to the fact that the readings taken included patches of oxide layers on both sides of the plates. All the readings taken exceeded the minimum thickness limit.

Following the ANDREA RTS inspection, a new robotic arm named "CALVIN" was developed by B & W, and designed for use from the boiler room (4" diameter vertical portholes) for visual inspection of the calandria vault. The ANDREA version EMAT and caliper could not be used with CALVIN because of the differences in physical requirements. Two new thickness measurement mounting fixtures using the same EMAT and LVDT sensors were built and incorporated into the CALVIN robot arm for Pickering RTS inspection. For the CALVIN measurements, the EMAT device was modified with a special preamplifier for driving long cables. The laboratory result showed that the EMAT device provided a good accuracy at a cable length of 100 feet.

On September 26, thickness measurements of one carbon steel RTS bracket in Pickering unit 4 were made by the CALVIN arm using access from the boiler room. Both the EMAT device and the caliper were used in this measurement. As with the previous Pickering unit 3 measurement data, the results from both techniques were consistent. All the readings taken exceeded the minimum thickness limit.

**S.P.I.D.E.R. (Self Propelled Inspection Device for Evaluating Reactors)**

S.P.I.D.E.R. is a new pressure tube inspection concept in which a special inspection head, equipped with electric motor drives, moves axially into the pressure tube from a modified closure plug module which is loaded into the channel by the fuelling machine.

The feasibility of a self-contained fuel channel inspection system has been investigated. Advantages of such a system include small size, ease of installation, increased probe positioning accuracy, and the possibility of simultaneous inspection of multiple fuel channels in a single reactor.

*Mechanical*

Initial test results indicate that in-channel motion control is feasible. A tap water immersion test was conducted on an unsealed underwater electric motor with an all stainless steel 16:1 gear reducer. The motor and gear reducer were operated intermittently with a 0.064 Nm (9 oz.in.) torque load at an output shaft velocity of 31.3 rpm. for a period of ten days. The water bath temperature was cycled between 50 deg.C and 25 deg.C and the motor was on for approximately 25% of the time. Some rusting was observed on two of the ten type 440C stainless steel bearings, however, only one of the bearings ceased to function normally. The motor and gear reducer continued to operate throughout the test in spite of the seized bearing due to a loose fit on the shaft. Wear on the gear teeth was low and the backlash in the gears remained negligible. It was also still possible to backdrive the motor-gear unit by applying a torque to the output shaft. It is anticipated that corrosion would not be a problem for pH 10 LiOH (fuel channel) applications.

*Electrical*

A prototype electronic drive has been developed for the above motor. Conventional drives for variable reluctance motors are unsuitable for inspection applications for two reasons. Firstly, low speed operation usually results in high vibration levels which make precise positioning difficult, and secondly, the drives generate high frequency electrical interference which can interfere with received ultrasonic signals. The laboratory prototype has shown that smooth slow speed operation can be achieved without generating large amounts of high frequency electrical interference. This drive uses power operational amplifiers acting as current sources to drive the motor stator coils. The three phase analogue waveform is generated by a 12 Mhz microcomputer board which uses an Intel 8044 microprocessor. The microcomputer accepts pulse and direction (or direct connection to an optical encoder) and produces a drive signal with a resolution of 2048 microsteps per revolution of the motor shaft. Open loop control of the motor is sufficiently stable to allow speeds as slow as 0.5 rpm and as fast as 5000 rpm. When combined with the 16:1 all stainless steel gear reducer, this system can drive a shaft at a constant speed of 20 rpm with a running torque of .44 N-m (3.9 in-lb). Surprisingly, there appears to be little difference between the performance of the motor in air and its performance in water. This suggests that the viscosity of water does not impose a significant loss of power even at 5000 rpm. or that energy losses due to viscosity are counterbalanced by performance gains due to improved damping. The possibility of increasing the power output has also been investigated. Components have been ordered for a high voltage driver which would take advantage of the fact that the motor would have continuous water cooling.

*Ultrasonic Encoder*

A new ultrasonic encoder has been designed to give an absolute reading of shaft position within a range of 360 degrees. The new design uses a single involute vane instead the four used by the older design. It uses a standard C.I.G.A.R. normal beam probe to enable it to operate for extended periods of time underwater and in high radiation fields. An IBM PC compatible interface board has been specified for driving the ultrasonic encoder and interfacing to a computer. An outside firm has agreed to design and manufacture the board and an order has been placed.

*Axial Drive*

Some effort has been made to incorporate a fail-safe feature into the current design of the axial drive to prevent it from getting stuck in the channel. This drive would have six 38 mm (1.5") wheels equally spaced around the diameter at each end. These wheels would each be driven, and would extend and retract together to accommodate any pressure tube diameter between 96 mm (3.75") and 114 mm (4.5"). At full speed, it would be able to traverse the length of a fuel channel in about 2.5 min.

*Rotary Signal Coupler*

A corrosion resistant slipring unit specification has been developed to provide direct electrical connections to ultrasonic probes on a rotating probe block. A slipring manufacturer has agreed to build a prototype, and an order has been placed. Previous attempts to use rotary transformers to solve the problem of underwater rotary signal coupling have not been successful.

*Helical Coaxial Cable*

A special helical cable had been designed for this purpose. This design incorporates twelve 50 ohm coaxes and 22 solid conductors. A cable manufacturer has made an attempt to manufacture this cable but with only partial success. Currently it is feasible to make such a cable with the coaxes only, but it is likely that the 22 solid conductors, which fit in the grooves between the coaxes, will be needed as well. To achieve this, further development will be needed. A request for proposals has been prepared and will be sent out in early 1991.

**RTS Bracket Thickness Measurement**

The IUL EMAT (ElectroMagnetic Acoustic Transducer) was used successfully on calandria vault ring thermal shield support brackets for measuring thickness in two Pickering A reactors using the CALVIN delivery arm. The measurements on both brackets showed very little corrosion had taken place, despite depressing videos. However, the device had proved highly unreliable during the year, so much so that a technician was required to take it back to the UK for repair. Nevertheless, the results obtained agreed well with the LVDT measurements taken, and the EMAT's autocorrelation function gave good confidence in the actual readings.

**Support to H/D Measurement**

Work has begun in assessing the feasibility of implementing the Tashiro method of measuring hydride concentration. Currently, the focus is on developing a method for heating and water exclusion from a short length of wet channel. Induction heating appears to be a logical choice for providing the heat energy. If a method for sealing can be found, it may be possible to achieve the water exclusion by boiling the water to steam.

Two prototype seal mechanisms have been built for laboratory testing. One is based on a high temperature silicone rubber disc which is flattened to actuate the seal and pulled into a cup-shaped form when the seal is to be released. The other is based on a high temperature silicone rubber O-ring. A mechanism applies force to the inside surface of the O-ring to actuate the seal. The O-ring approach is somewhat more complex, but appears to require much less energy to actuate. It has been demonstrated that the seal can be operated with an underwater gearmotor that has previously been developed at Research.

A preliminary analysis of the heating requirements indicates that 3 kW of heating energy would be needed to achieve a pressure tube temperature of 400 degrees C in ten minutes. An electromagnetic induction heating coil is being designed to provide this heating using approximately four C.I.G.A.R. type co-ax cables. This assumes that it will be possible to use a capacitor at the coil to optimize the power factor.

A high frequency induction power supply has been specified for the induction coil and an order has been placed. It is designed to deliver 10 kW of energy at 50 - 125 kHz. The induction heating development is being carried out by the Stations & Underground Section at Research.

**Pickering BLIP Inspection Software**

In mid 1990, Central Production Services (CPS) performed an inspection of approximately 300 pressure tubes in Pickering Unit 4 to identify tubes containing cracked hydride blisters. This inspection was performed with data acquisition, processing, and display software written in the first half of 1990 by members of the Automated Systems Technology Section. This software, which required approximately three man-months to write, was based upon the PIPE and SLAR data acquisition systems developed in previous years. In the field, both hardware and software performed well and the inspection was completed on schedule.

**Compumotor Noise Filters**

For several years, electrical noise generated by Compumotor Stepping Motor Systems has posed serious problems during ultrasonic inspections performed on scanning rigs that employed Compumotor drives. Electrical noise invaded the sensitive ultrasonic equipment and decreased the signal to noise ratio significantly. After attempting to solve this problem in-house, an electronics design company, CSI Electronics, was contracted to assess the problem and to construct a motor filter that would reduce or eliminate the radiated electrical noise. CSI designed and installed a filter that produced excellent results which are recorded in Research Report # 90-277-K.

Steam Raising & Handling

**Fretted Bruce 6 Steam Generator Tubes**

Half a dozen fretted steam generator tubes removed from Bruce 6 were supplied by CPS for ultrasonic examination to verify that no cracking was present. Up to 40% of the tube wall had been lost in some cases. The multi-element SG inspection system was used to scan all the fretted areas, but no significant defects were found using the angle beam transducers.

**Sludge Layer Thickness Measurements**

Digital spectral analysis of ultrasonic waves was used to measure the sludge layer thickness on the outside of steam generator tubes. Thicknesses ranged from 70 to 700 microns. The sludge provided by CRNL proved to be very attenuative and of low velocity.

Following previous work, the frequency spectrum of the returned normal beam signal was evaluated using a fast Fourier transform, followed by filtering, windowing and decimating. The spectrum with sludge present was divided by a reference spectrum without sludge, and the time-thickness of the sludge estimated from dips in the spectrum. In practice, the sludge proved so similar in acoustic impedance to the water that no readings were possible from the primary side, though successful readings were obtained from the secondary side.

More recently, a Dutch company recommended measuring sludge thickness depth by measuring the thickness of the steam generator wall, and subtracting the metal thickness. However, preliminary tests on thin sludge layers on Pickering 2 removed tubes suggested that this approach would be unsatisfactory due to acoustic impedance problems. Consequently, modifications are being made to current transducers, and a delivery system will be adapted to collect waveforms from the stations. Then, either simple wall thickness measurements, spectral analysis or L1 norm deconvolution will be tried to measure sludge thickness.

**A Special Probe Pan for Pickering Low Pressure (LP) Turbine Disc Inspection**

In June 1990, CPSD requested that a special ultrasonic probe pan or probe manipulator be developed and integrated to the existing L.P. turbine inspection equipment "BONNIE" system for the inspection of Hearn Unit 5 LP#1 rotor (NEI-Parsons design). Turbine rotor discs can be susceptible to stress corrosion cracking in the bore and keyways.

Limited access between certain L.P. turbine discs (approx. 15 mm groove) was the main reason for building the device. Two special probe pans (Left and right hand versions) were built to accommodate the inspection. They were designed to be attached to the wrists of the Bonnie arms. The main function of these probe pans is to allow the ultrasonic transducers to access the sloped web face of the discs and to provide a proper probe-web surface contact. The probe pans have an overall thickness of 12.7 mm. CPSD personnel reported that these probe pans met the design requirements and were successfully used in Hearn rotor inspection.

**COG: Automated Ultrasonic Inspection Technique Development For Steam Generator Tube**

The investigations required to develop a rapid ultrasonic inspection technique continue. Work has been focusing on the development of a multiple element axial-facing ultrasonic probe for circumferential fault detection, and a separate normal beam probe for wall thickness measurement and sludge pile detection.

Preliminary testing and evaluation of commercial 16 element ultrasonic probes from Krautkramer-Branson indicated that the sensitivity of these probes was acceptable. A special 16 element probe from the manufacturer to suit our inspection requirements was purchased. The possibility of using the same probe for inspection of Darlington, Bruce and Pickering tubes will be investigated.

Evaluation of the NUCON rotating probe continues. The test results indicated that the sensitivity of the probe was not adequate for our requirements. We are currently negotiating with NUCON about the possibility of improving this probe's inspection quality or expanding the capability of this probe to meet our requirements for broach plate deposit and U-bend inspection for Pickering & Bruce type tubes.

The development of a multi-element head that uses curved, line focused probes constructed from a co-polymer material continues. The objective of this work is to develop an inspection head that may provide close to 100 percent coverage of the tube being inspected. A number of sample probes made by a local vendor are now being investigated. There are a number of technical problems associated with the construction of such an inspection head, but steady progress is being made.

A special probe drive mechanism, which consists of a Zetec pusher-puller and a cable pick-up wheel, has been designed for field use. This current prototype will be capable of performing inspection in the area at and above the tube sheet including the entire straight length of a tube. Fabrication of this assembly is currently underway.

There may be an opportunity for us to test this UT system at Darlington in 1991 and at Point Lepreau, New Brunswick power plant in 1992. We are now preparing a plan to meet this schedule and to ensure that the automated inspection equipment being developed can be used for inspecting the Darlington type tubes. Work will be done to investigate the possibility of using similar UT probes for both Pickering and Darlington S.G. tubes.

## NUCLEAR WASTE

### High Level Waste & Irradiated Fuel

**Concrete Integrated Container - Delivery System for Welding**

A major effort has been initiated to identify the technologies required for performing the final closure welding of the Concrete Integrated Container (CIC) for storage and transportation of spent nuclear fuel. In addition to determining the optimum welding process and procedures for this task, an essential requirement is to determine the most appropriate approach to performing this welding remotely, with minimum operator involvement. An extensive review was prepared of possible options regarding CIC closure welding mechanization or automation, taking into account performance requirements and recognizing the limited time and money available for extensive development work. Decisions are to be made early in

1991 regarding the approaches to be taken, and it is expected that equipment assessment and laboratory testing will be undertaken during the year, leading to final hardware specifications by year end.

**Automated System for Nuclear Fuel Waste Disposal Container Closure**

For some years, an ongoing project within the Metallurgical Research Department has been the development of welding technologies for nuclear fuel waste disposal. In 1990, work centred on the establishment of a remote welding capability for this application. This has concentrated on the use of a commercial laser/camera sensor system (from MVS) for high precision seam tracking. In this system a laser beam is fanned out by a columnar lens and projected through a slit as a line onto the weld joint. A camera, set at a slight angle, views and digitizes the resulting image. This provides fully quantitative 3D information about the weld joint, which is then used to control weld torch position so that the appropriate weld path is accurately followed.

The laser sensor originally purchased generated a relatively long laser stripe (75 mm). This has been replaced by a sensor with a smaller field of view (30 mm) which has resulted in significantly improved resolution and seam tracking accuracy. The software to perform realtime seam tracking with the new sensor, interfaced to a modified Dimetrics weld head, has been essentially completed. The system's capabilities have been demonstrated, but without a welding arc, because of the disruption caused by high-frequency arc.start. Work has been initiated to incorporate a welding power supply equipped with a commercial touch-start arc ignition system for demonstration purposes. This is relatively straightforward for manual welding operations, but it is complex for an automated system because it requires a variety of synchronized actions, including vertical motion of the welding torch (downwards to establish contact, then upwards to draw the arc) and power supply current control to slope up the welding current while the arc is being established. A separate computer module is being assembled to provide this capability. At the same time, the alternative of purchasing a sophisticated welding power supply which already incorporates these capabilities, is being considered.

Full demonstration of the automated welding system for fuel waste container closure is anticipated in 1991. Further work is planned regarding the use of the laser sensor in other applications, particularly for seam tracking and post-weld inspection during the end-fitting welding required during retubing.

**Remote Inspection**

A video was made of the PUMA robot mapping and inspecting a titanium diffusion bond on a prototype nuclear used fuel container final closure weld. After some programming effort, the robot could reliably and accurately map and scan the bond, detecting the intentionally-embedded defects therein. The results showed that remote, reliable inspection is feasible with current technology, though this robotic approach is rather slow.

**Dry Storage Container**

As part of the spent fuel Dry Storage Container program, the Automated Systems Technology Section and the Welding Unit were asked to design a lid/body closure weld and to design automated systems that could make the weld and ultrasonically inspect it. A great deal of effort was spent on selecting the geometry of the weld and manufacturing samples to test both weld and ultrasonic inspection techniques. Inspection delivery systems were evaluated, schedules were prepared, and cost estimates were made. At the end of 1990, further work on the inspection system was awaiting project approval; however, at the beginning of this year, the weld geometry was re-evaluated and this may have a significant impact on the entire inspection procedure. At this time, radiography is also being considered as an alternative to ultrasonic inspection.

## THERMAL GENERATION

### Steam Raising & Handling

**NDE For Creep Cavitation in Steels**

A variety of ultrasonic and magnetic techniques were investigated on thick section specimens from Lakeview to measure creep cavitation. These include velocity, attenuation and nonlinear ultrasonics, plus resistivity methods. The resistivity approach (developed by CPS at OHRD) was tested at Lakeview, with about 70% success compared with the replica approach. The ultrasonic techniques, tried mainly on weld cross sections, showed that there were small changes in the various parameters. However, it proved very difficult to differentiate the changes due to porosity from those due to material variations in the HAZ.

## HYDRAULIC GENERATION

**Hydraulic Station Headgate Roller Path Repair**

In August 1990, a shutdown was scheduled at Abitibi Canyon GS which was to include overhaul of headgate components, including rebuilding the worn down area along the roller path used by the headgate wheels. Initially, the Welding Unit identified an appropriate welding consumable (Stoody 110-0) for this buildup and established welding procedural data. Subsequently, mechanization of the Abitibi Canyon repair was shown to be viable and emphasis shifted to identifying appropriate equipment and techniques. At the same time, a longer term project was initiated regarding mechanization and automation as applied to headgate roller path repair in general, including implementation of the existing turbine runner repair robot to this application.

A 2 m high full scale mockup of the roller path and its surrounding support structure was assembled. Mechanized plasma arc gouging and P-GMA welding were subsequently successfully demonstrated on the mockup. Grinding appeared to impart excessive forces on the combination Gullco Kat and Bug-O mechanized

setup, however. Thus, final grinding was done either manually or, preferably, with the track-mounted compact robot developed for turbine runner repair. A second roller path mockup was assembled, which included concrete and full instrumentation for distortion and residual stress measurement. Testing results indicated a potential problem with excessive distortion and/or residual stress buildup during the gouging and welding steps of the repair. As a result, it was decided that roller path weld repair at Abitibi Canyon was an inappropriate repair technique and the development work was therefore stopped.

**Robotic Repair of Hydraulic Turbine Runners**

Following last year's successful field trial of the robotic system, a new stage of development was initiated which will eventually lead to a complete system being available for permanent field use. Initial schedule objectives were deferred due to efforts being diverted to the 'Hydraulic Station Headgate Roller Path Repair' project described above.

A plasma arc gouging capability was added to the robotic system as a preferred option to air-arc gouging. Problems were encountered with disruptive effects on the robotic system electronics due to the plasma arc's high frequency arc start. Grounding, shielding and other improvements to the robotic system and L-TEC gouging power supply have resolved the problems during arc start.

Improvements have also been made to the welding process with the addition of a Hobart Ultra Arc 350 power supply and necessary adaptive control circuitry. This was to allow the use of a broader range of welding consumables, including Stellite and IRECA. At Hydro-Quebec, work is continuing towards the development of a second generation "super-compact" robot; informal collaboration is being maintained between the two utilities to ensure compatibility in the two parallel streams of development.

A U.S. patent application filed by Ontario Hydro and Hydro Quebec for the robotic system was allowed in April, 1990, entitled "Method And Apparatus For Automatically Sensing The Configuration Of A Surface Area And Effecting A Work Function Thereon". Discussions including personnel from New Business Ventures and Law Division are ongoing with Hydro-Quebec regarding eventual commercialization of the robotic system.

**Robotic Repair of Hydraulic Turbine Runners**

The primary area of concentration will be the development of a field rugged plasma gouging system and integration of this system with the "super-compact" robot being developed at Hydro Quebec. In addition, work will continue on the eventual replacement of the main computer with a less expensive industrial and field rugged computer.

1991 Work Program

The Advanced Systems Technology Section work program will largely be a continuation of the 1990 program. The NDE Unit will continue its emphasis on pressure tubes, with main projects on hydride measurement, defect depth measurement, signal processing and on-power inspection. Specifically, a prototype ultrasonic hydride monitoring system should be available for Pickering 4 in August. A method of detecting tight garter springs should be tested on CIGAR in the Spring. Further work will be performed on analyzing defects, as appropriate. Work on deconvolution will continue for both eddy current and ultrasonics.

Systems such as CIGAR, SLAR and BLIP (eg for Darlington 2) will be supported, as needed. The BHWP patch scanner should be delivered in the Spring. The automated steam generator inspection system will be demonstrated, and work on measuring sludge thickness will continue.

In Automated Systems, work will continue on projects such as engineering the Tashiro method for measuring hydride concentration, and on SPIDER. Pickering A remote inspections will continue, and STEM and other tooling modifications will be built/provided, as required. A super-compact robot will be developed for repairing turbine runners, with Hydro-Quebec.

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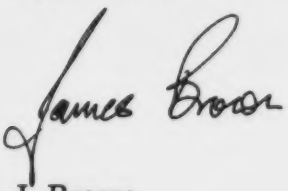

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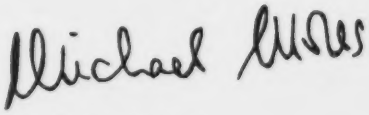

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